PROPOSED CLAIMS

1. (Currently Amended) A real-time *in-situ* model-based chemical-mechanical planarization (CMP) controller, comprising:

a dynamic mathematical model of a CMP system to be controlled in response to *in-situ* data from a plurality of real-time sensors in said CMP system, said mathematical model comprising any of a physics-based model~~,~~ and an empirical model;

computer simulation means for evaluating said mathematical model; and

means for validating said mathematical model using any of real-time, *in-situ* data and ex-situ data from said CMP system.

2. (Currently Amended) The controller of Claim 1, further comprising:

a reduced mathematical model for real-time *in-situ* CMP system control.

3. (Currently Amended) The controller of Claim 1, said mathematical model comprising any of:

a real-time removal rate model of a CMP system; and

a real-time thermal model of a CMP system.

4. (Original) The controller of Claim 1, wherein modifications of said CMP system can be evaluated with said mathematical model via computer simulation prior to any CMP system modifications.

5. (Currently Amended) A method for producing a real-time *in-situ* model-based chemical-mechanical planarization (CMP) controller, comprising the steps of:

generating a dynamic mathematical model of a CMP system to be controlled in response to *in-situ* data from a plurality of real-time sensors in said CMP system said mathematical model comprising any of a physics-based model~~,~~ and an empirical model;

evaluating said mathematical model with a computer simulation; and

validating said mathematical model using any of real-time *in-situ* data and ex-situ data from said CMP system.

6. (Currently Amended) The method of Claim 5, further comprising the step of:

controlling said CMP system in real-time with a reduced mathematical model.

7. (Currently Amended) The method of Claim 6, said mathematical model comprising any of:

a real-time removal rate model of a CMP system; and

a real-time thermal model of a CMP system.

8. (Original) The method of Claim 6, further comprising the step of:

evaluating said CMP system with said mathematical model via computer simulation prior to any CMP system modifications.

9. (Currently Amended) In a model-based chemical-mechanical planarization (CMP) controller, said model comprising a dynamic mathematical model of a CMP system to be controlled in real-time, said mathematical model comprising any of a physics-based model, an empirical model, and any combination thereof, said mathematical model produced by open-loop and closed-loop techniques comprising use of both a computer simulation means for evaluating said mathematical model and means for validating said mathematical model using any of real-time, *in situ* data and ex-situ data from said CMP system, said controller comprising:

a reduced mathematical model for CMP system control in response to *in-situ* data from a plurality of real-time sensors in said CMP system.

10. (Original) A method for controlling a chemical-mechanical planarization (CMP) system, comprising the steps of:

providing an integrated model-based pressure-temperature-velocity-slurry flow control system comprising real-time mode identification, real-time gain estimation, and real-time control, said model comprising a plurality of component models of said CMP system;

said control system processing *in-situ* data from a plurality of real-time sensors in said CMP system; and

said control system producing real-time commands to a plurality of actuators to control said CMP system.

11. (Original) The method of Claim 10, said model comprising:

an advanced dynamic CMP model having externally controllable variables as inputs;

wherein said model predicts a material removal rate and temperature as a function of time and location on a wafer.

12. (Original) The method of Claim 10, wherein said component models comprise any of:

a contact mechanical model for predicting contact pressure and relative velocity between a polishing pad and a wafer surface;

a chemical and mechanical model for predicting local removal rate as a function of local slurry, pad, and wafer properties;

a transport model for predicting distribution of slurry, pad, and wafer properties across a wafer/pad interface; and

a thermal model for predicting temperature distribution at said wafer/pad interface necessary for accurate chemistry and transport modeling.

13. (Original) The method of Claim 12, wherein said models are interdependent.

14. (Original) The method of Claim 11, wherein said inputs comprise any of:

applied pressures, slurry flow rate, and wafer/platen velocity.

15. (Original) An apparatus for controlling a chemical-mechanical planarization (CMP) system, comprising:

a plurality of real-time sensors in said CMP system;

a plurality of actuators for controlling said CMP system; and

an integrated model-based pressure-temperature-velocity-slurry flow control system comprising real-time mode identification, real-time gain estimation, and real-time control;

said model comprising a plurality of component models of said CMP system;

said control system processing *in-situ* data from said real-time sensors in said CMP system; and

said control system producing real-time commands to said actuators to control said CMP system.

16. (Original) The apparatus of Claim 15, said model comprising:

an advanced dynamic CMP model having externally controllable variables as inputs;

wherein said model predicts a material removal rate and temperature as a function of time and location on a wafer.

17. (Original) The apparatus of Claim 15, wherein said component models comprise any of:

a contact mechanical model for predicting contact pressure and relative velocity between a polishing pad and a wafer surface;

a chemical and mechanical model for predicting local removal rate as a function of local slurry, pad, and wafer properties;

a transport model for predicting distribution of slurry, pad, and wafer properties across a wafer/pad interface; and

a thermal model for predicting temperature distribution at said wafer/pad interface necessary for accurate chemistry and transport modeling.

18. (Original) The apparatus of Claim 17, wherein said models are interdependent.

19. (Original) The apparatus of Claim 16, wherein said inputs comprise any of:

applied pressures, slurry flow rate, and wafer/platen velocity.

20. (Original) A chemical-mechanical planarization (CMP) system controller, comprising:

a temperature control module for controlling average polishing pad temperature responsive to temperatures measured by any of an *in-situ* temperature sensor and a thermal model;

a pressure profile control module for controlling individual zone pressures for a multi-zone pressure CMP process to provide *in-situ* pressure feedback using *in-situ* wafer thickness measurements, as obtained with an *in-situ* thickness sensor, to adjust pressures *in-situ*;

a slurry flow control module for controlling slurry flow to said CMP system;

a motor velocity control module; and

a post scaling for temperature control module for post-scaling all control variables, wherein net temperature increase or decrease from individual control variables is counteracted by total scaling of all control variables.

21. (Original) The controller of Claim 20, said temperature control module comprising:

a mode shape identification element for defining maximum planarization achievable by said CMP system;

a master control loop for indirectly controlling average wafer/pad temperature by actuating any of input pressures, slurry flow rate, and wafer/pad velocities; and

a dynamic temperature model and a dynamic temperature reference model, both of which describe evolution of average wafer/pad temperature over time;

wherein said dynamic temperature model describes wafer/pad temperature, is optional, and can be replaced by a temperature measurement if a temperature sensor is available; and

wherein said dynamic temperature reference model describes desired or reference wafer/pad temperature and is driven by said master control loop;

wherein wafer/pad temperature is predicted as a function of any of input pressures, slurry flow, and wafer/pad velocity.

22. (Original) The controller of Claim 20, wherein a motor electrical power sensor is used for temperature sensing in lieu of a temperature sensor.

23. (Original) The controller of Claim 21, further comprising:

a pressure slave loop comprising a feedback controller combined with feedforward control;

24. (Original) The controller of Claim 21, further comprising:

any of a slurry flow and a velocity slave loop, each of which is fed by set point values from said master control loop;

wherein any of slurry flow and velocity are used to control wafer/pad temperature.

25. (Original) The controller of Claim 20, said pressure profile control module comprising:

a zone-averaging model for extracting more-or-less-independent thickness information from a measured wafer profile for each of a plurality of pressure zones;

a tracking error calculation and reference generator for generating a feasible feedback control error for each of said plurality of pressure zones;

a multi-input multi-output pressure feedback controller for generating real-time pressure commands from said feasible feedback control error for each of said plurality of pressure zones; and

a gain estimation model for adjusting the gain of said multi-input multi-output pressure feedback controller using a real-time estimation of a measured CMP system removal-rate.

26. (Original) The controller of Claim 25, wherein said tracking error calculation and reference generator provides any of:

an absolute thickness control mode, wherein a reference value is an external signal specifying a desired thickness and thickness removal rate, at each point in time, wherein absolute thickness and polish rate in each zone are equal to an external reference thickness and polish rate for each zone, respectively; and

a uniformity control mode, wherein a reference value is equal to measured average thickness in one of said zones at each point in time to control uniformity of said wafer by making thickness in all other zones equal to thickness in reference zones.

27. (Original) The controller of Claim 20, said motor velocity control module further comprising:

a kinematic model for determining how motor velocity affects a distributed removal rate to control wafer and pad motor velocities.

28. (Original) The controller of Claim 20, wherein said controller is augmented with any of run-to-run control, iterative learning control, and adaptive control.

29. (Original) A method for controlling a chemical-mechanical planarization (CMP) system, comprising the steps of:

controlling average polishing pad temperature responsive to temperatures measured by any of an *in-situ* temperature sensor and a thermal model;

controlling individual zone pressures for a multi-zone pressure CMP process to provide *in-situ* pressure feedback using *in-situ* wafer thickness measurements, as obtained with an *in-situ* thickness sensor, to adjust pressures *in-situ*;

controlling slurry flow to said CMP system;

controlling motor velocity; and

post-scaling all control variables (pressure, slurry flow rate, velocity), wherein net temperature increase or decrease from individual control variables is counteracted by total scaling of all variables.

30. (Original) The method of Claim 29, said temperature control step comprising the steps of:

defining maximum planarization achievable by said CMP system;

indirectly controlling average wafer/pad temperature by actuating any of input pressures, slurry flow rate, and wafer/pad velocities; and

providing a dynamic temperature model and a dynamic temperature reference model, both of which describe evolution of average wafer/pad temperature over time;

wherein said dynamic temperature model describes wafer/pad temperature, is optional, and can be replaced by a temperature measurement if a temperature sensor is available; and

wherein said dynamic temperature reference model describes desired or reference wafer/pad temperature and is driven by said master control loop;

wherein wafer/pad temperature is predicted as a function of any of input pressures, slurry flow, and wafer/pad velocity.

31. (Original) The method of Claim 29, further comprising the step of:

using a motor electrical power sensor for temperature sensing in lieu of a temperature sensor.

32. (Original) The method of Claim 30, further comprising the step of:

providing a pressure slave loop comprising a feedback controller combined with feedforward control;

33. (Original) The method of Claim 30, further comprising the step of:

providing any of a slurry flow and a velocity slave loop, each which is fed by set point values from said master control loop;

wherein any of slurry flow and velocity are used to control wafer/pad temperature.

34. (Original) The method of Claim 26, said zone pressure control step comprising the step of:

extracting more-or-less-independent thickness information from a measured wafer profile for each of a plurality of pressure zones;

generating a feasible feedback control error for each of said plurality of pressure zones;

generating real-time pressure commands from said feasible feedback control error for each of said plurality of pressure zones; and

adjusting the overall level of said real-time pressure commands using a real-time estimation of a measured CMP system removal-rate.

35. (Original) The method of Claim 34, said feedback control error generating step producing a tracking error calculation and reference generator which provides any of:

an absolute thickness control mode, wherein a reference value is an external signal specifying a desired thickness and thickness removal rate, at each point in time, wherein absolute thickness and polish rate in each zone are equal to an external reference thickness and polish rate for each zone, respectively; and

a uniformity control mode, wherein a reference value is equal to measured average thickness in one of said zones at each point in time to control uniformity of said wafer by making thickness in all other zones equal to thickness in reference zones.

36. (Original) The method of Claim 29, said motor velocity control step further comprising the step of:

determining how motor velocity affects a distributed removal rate to control wafer and pad motor velocities.

37. (Original) The method of Claim 29, further comprising the step of:

augmenting system control with any of run-to-run control, iterative learning control, and adaptive control.